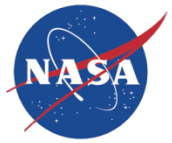

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Project Orion Abort Flight Test

The Range Safety Debris Catalog Analysis in Preparation for the Pad Abort One Flight Test

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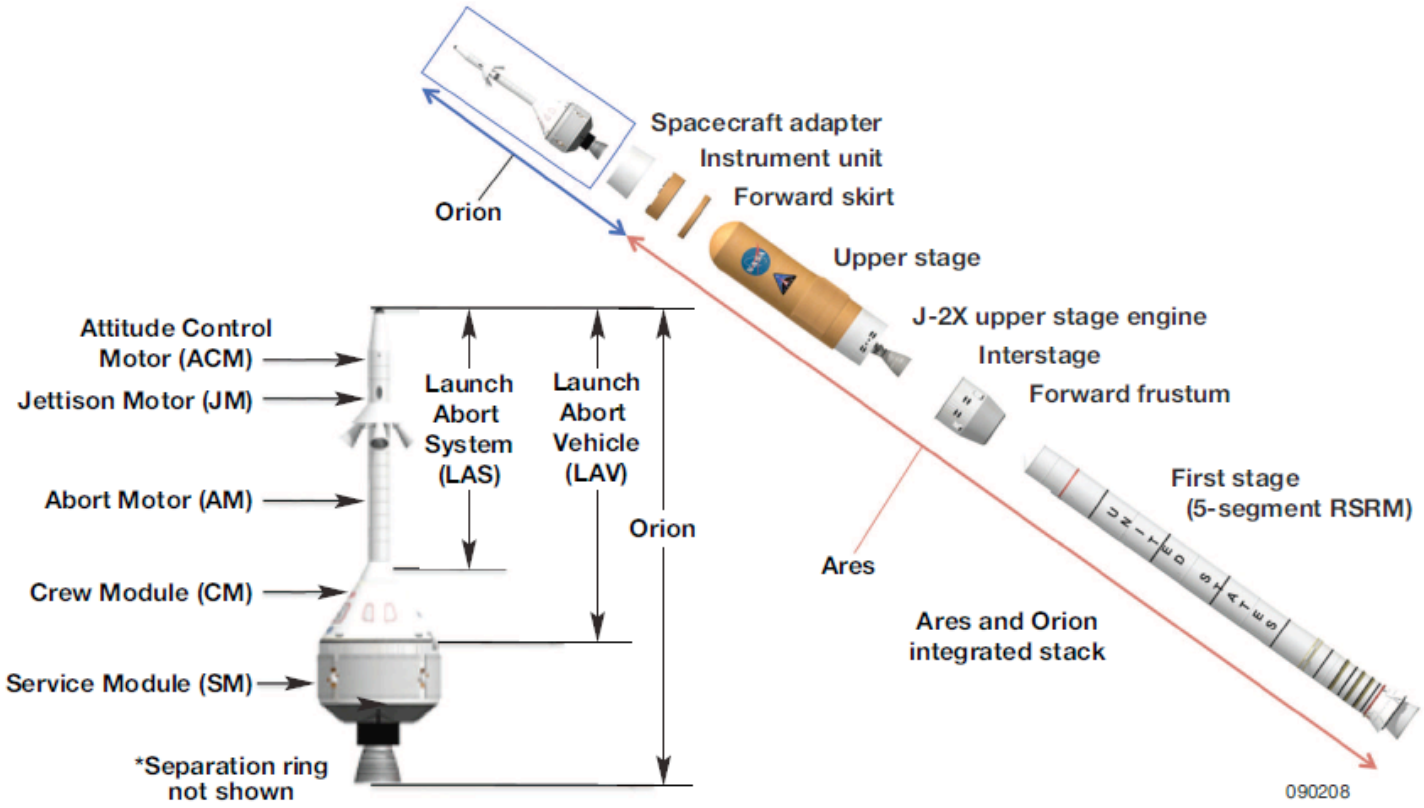
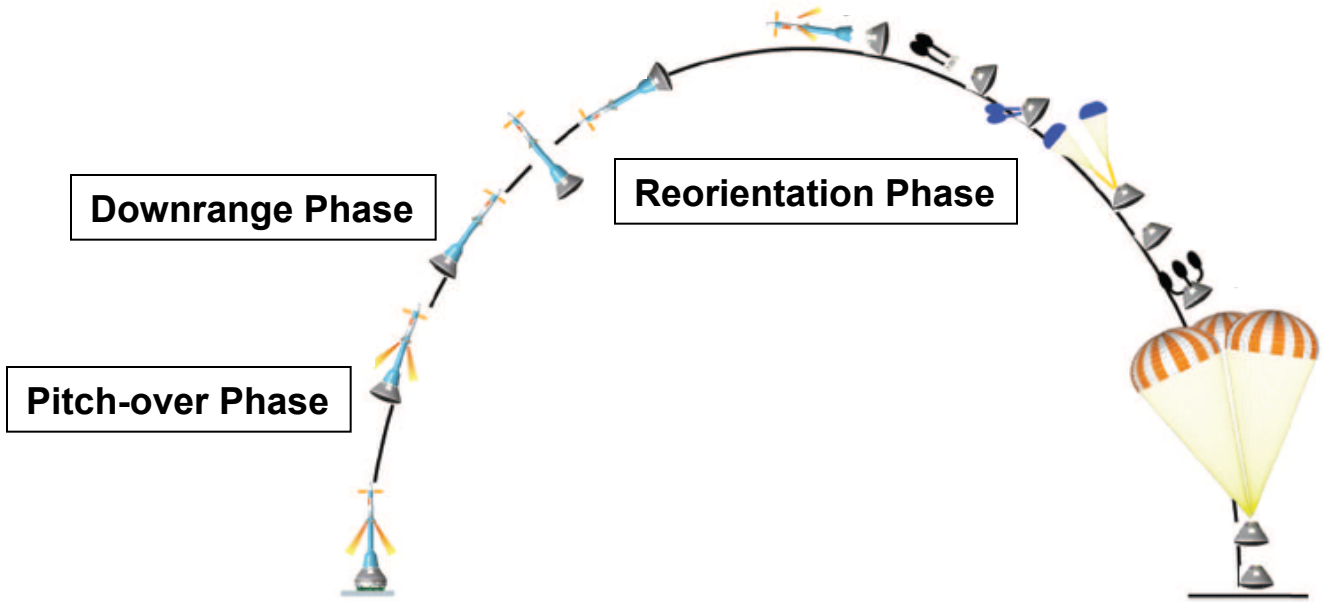
Constellation, Orion Overview

- Space Shuttle set to retire in the near future
- Constellation to succeed the Space Shuttle Program
- Orion Program consists of crewed portion of Constellation



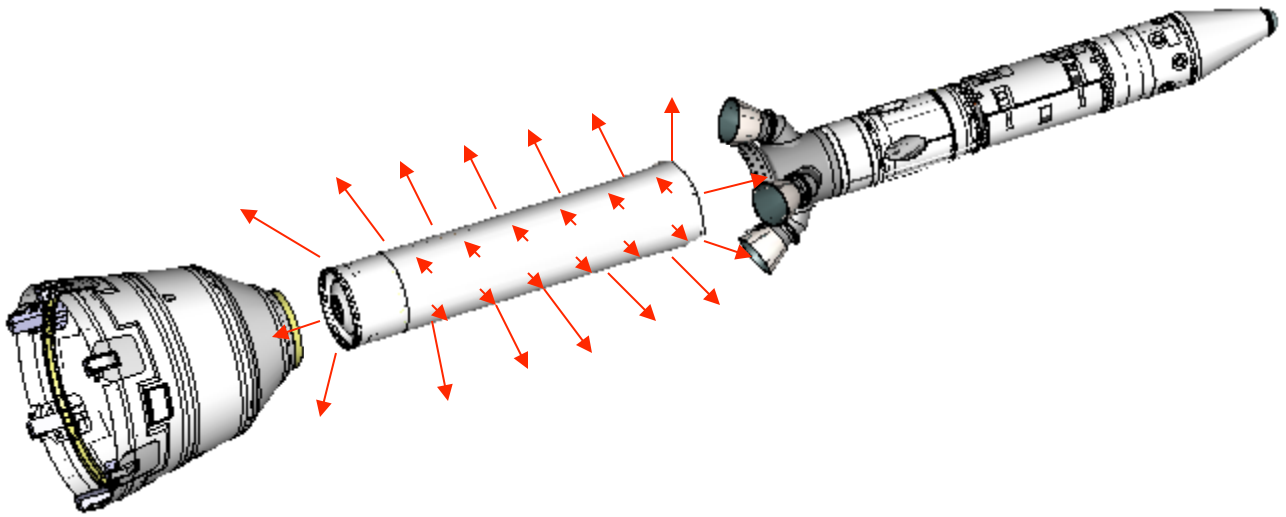
Abort Flight Test, PA-1 Overview

- Abort Flight Test (AFT) Program dedicated to flight testing the Launch Abort System (LAS)
- LAS provides the crew with an egress system in the event of an emergency
- AFT includes a series of flight tests (pad and ascent) that Orion will leverage in developing the LAS
- Pad Abort One (PA-1) is the first flight test scheduled for early 2010, at White Sands Missile Range (WSMR), New Mexico



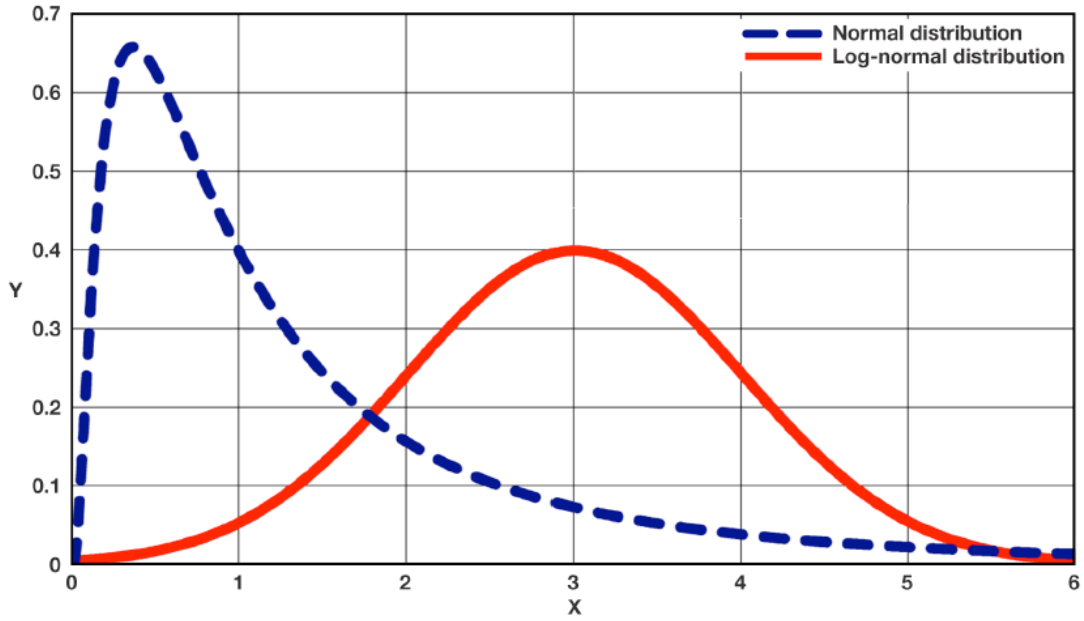
Debris Catalog Analysis

- With each flight test a Range Safety Data Package is assembled to understand the potential consequences of various failure scenarios
- Debris catalog analysis considers an overpressure failure of the Abort Motor and the resulting debris field created
  1. Characterize debris fragments generated by failure: weight, shape, and area
  2. Compute fragment ballistic coefficients
  3. Compute fragment ejection velocities



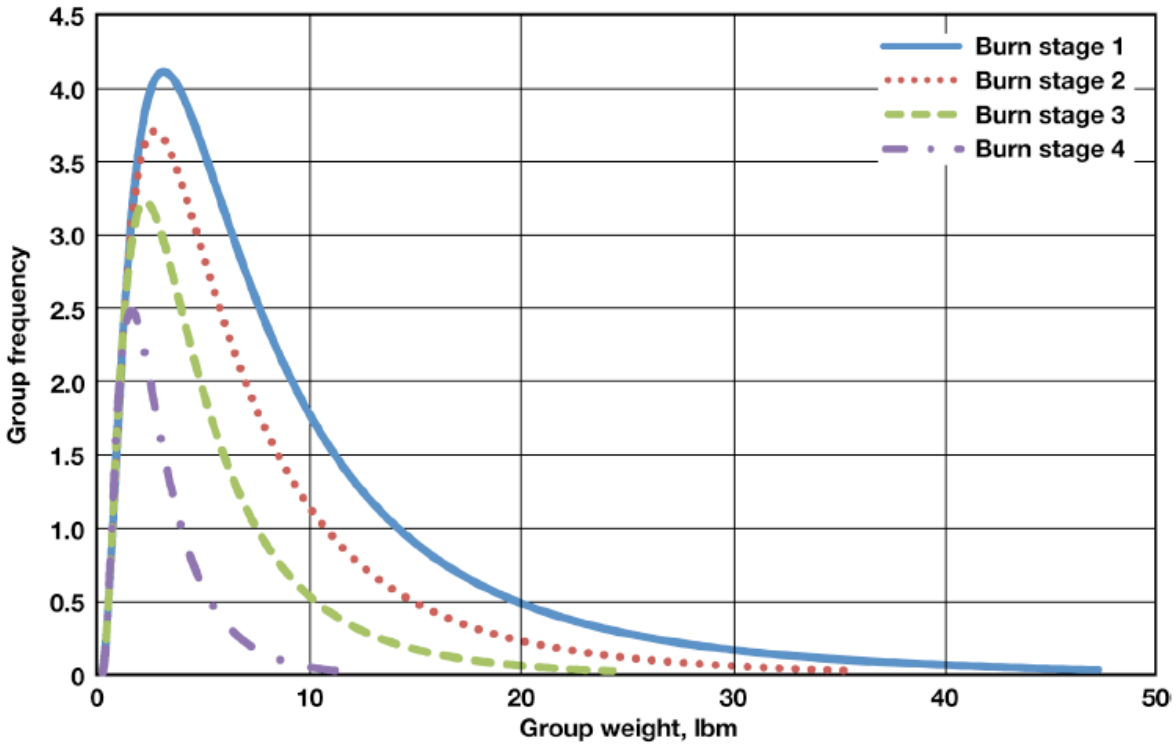
Fragment Distribution

- Propellant only distribution – motor case fragments considered negligible due to composite material
- Statistical model is applied to characterize AM fragments created in overpressure failure
- Previous investigations of solid rocket launch vehicle failures reveal consistent trends in fragment distribution
- Log-normal Distribution can be used to represent fragment distribution



Fragment Distribution

- Distribution model applied at four points, burn stages, along the PA-1 trajectory
- Burn stages correspond to amount of propellant burned at time of destruct:
  - 1: 0 % Burned (on the pad)
  - 2: 25% Burned
  - 3: 50 % Burned
  - 4: 75 % Burned



Ballistic Coefficient Computation

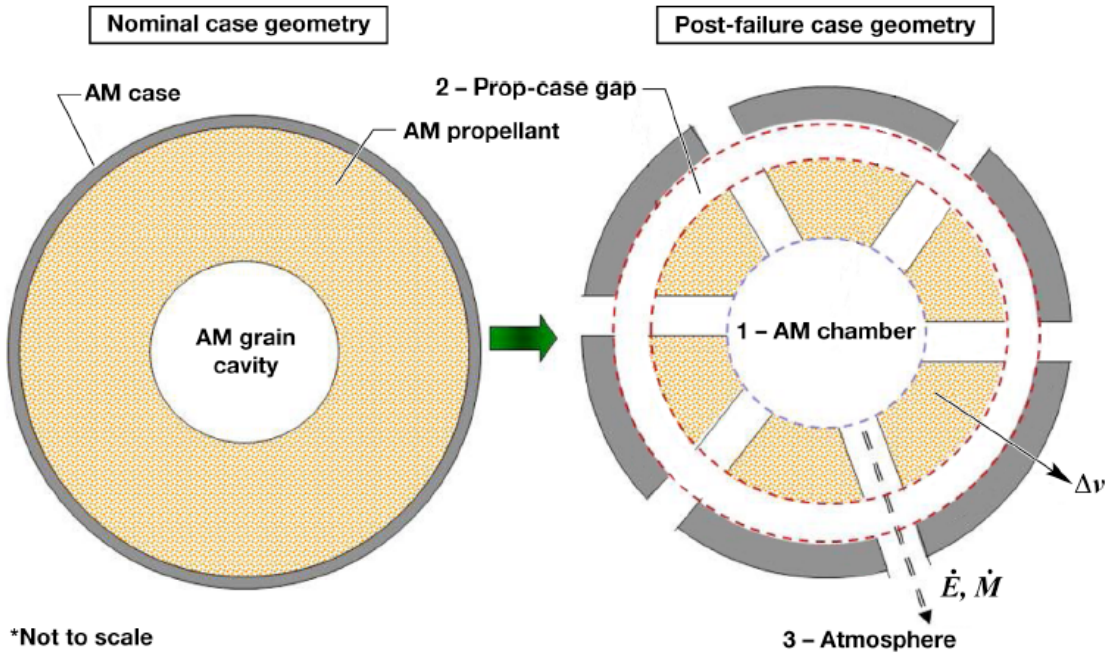
- Function of mass, area, and drag coefficient:

$$\beta = \frac{m}{c_d A}$$

- Lower drag coefficients and higher mass to area ratios yield higher ballistic coefficients
- Higher ballistic coefficient items travel farther downrange
- Mass and area of fragment obtained during catalog distribution determination
- Drag coefficient taken from accepted aerodynamic data

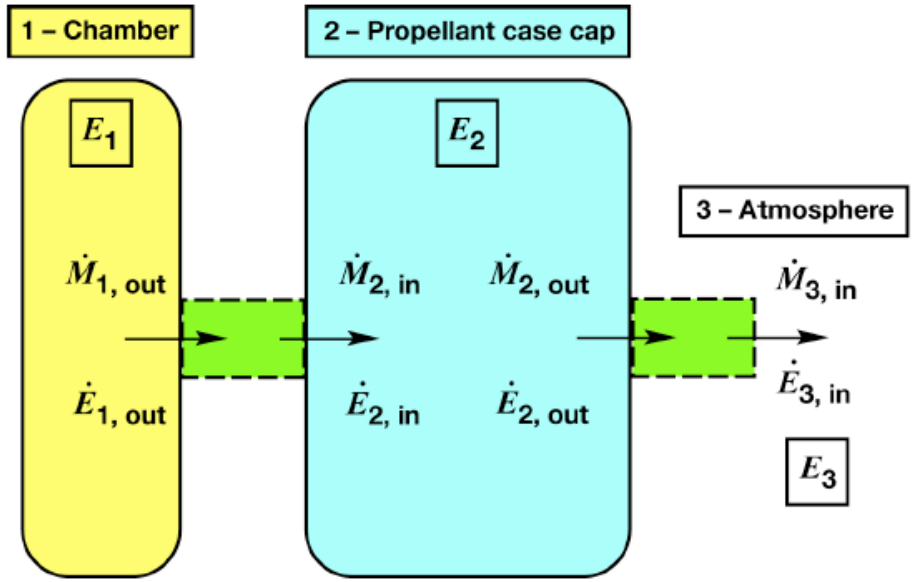
Ejection Velocity Model

- Energy transfer approach
  - Potential energy from overpressure is converted into fragment kinetic energy
  - Pressure wave results, distribution of force is applied to fragments
  - Fragments attain an ejection velocity within a few microseconds
- Assume that case debonds from propellant creating a pressurized control volume



Velocity Model Energy Balance

- Three control volumes:
  - motor chamber
  - propellant-case gap
  - atmosphere



- For each control volume:

$$\dot{E}_i = \dot{E}_{i,flowin} - \dot{E}_{i,flowout} - \dot{W}_{fragment}$$

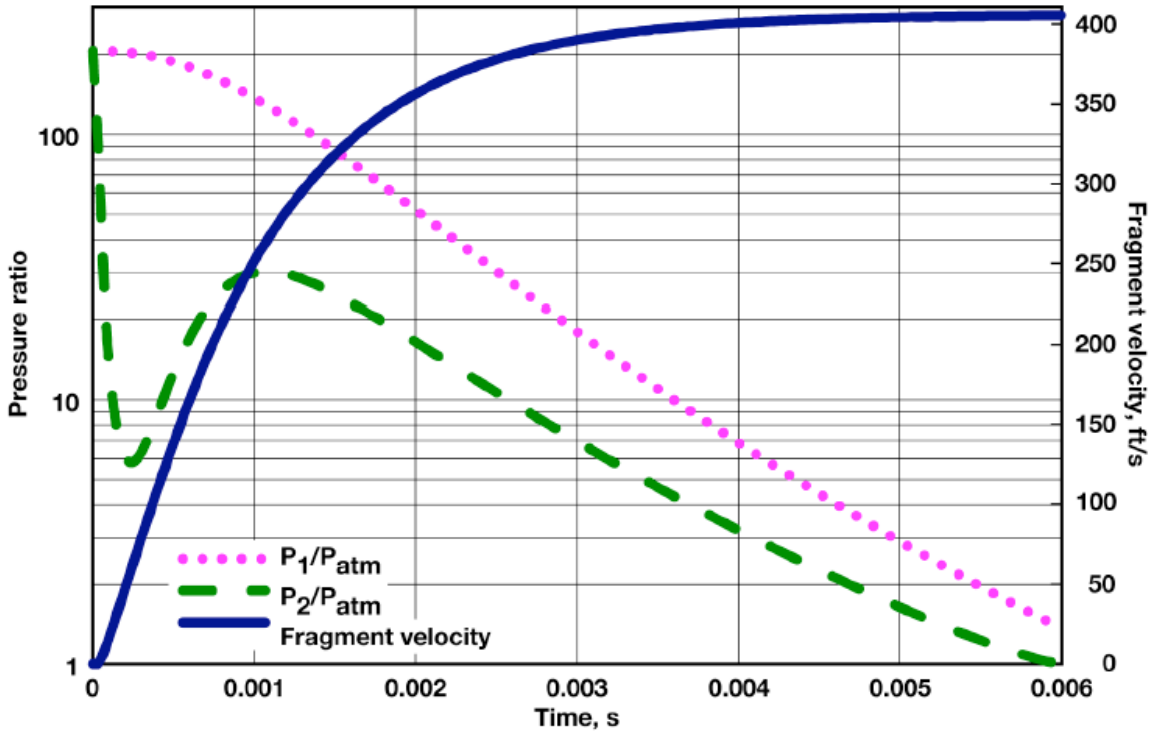
- Assume that energy can only flow out of the chamber and into the atmosphere:

$$\dot{E}_{1,flowin} = 0$$

$$\dot{E}_{3,flowout} = 0$$

Final Ejection Velocity

- Pressure of each control volume can be calculated from corresponding energy states
- Force applied to fragment is obtained from pressure distribution
- Acceleration and velocity are derived from force
- Simulation is propagated until pressures reach equilibrium and velocity asymptotes



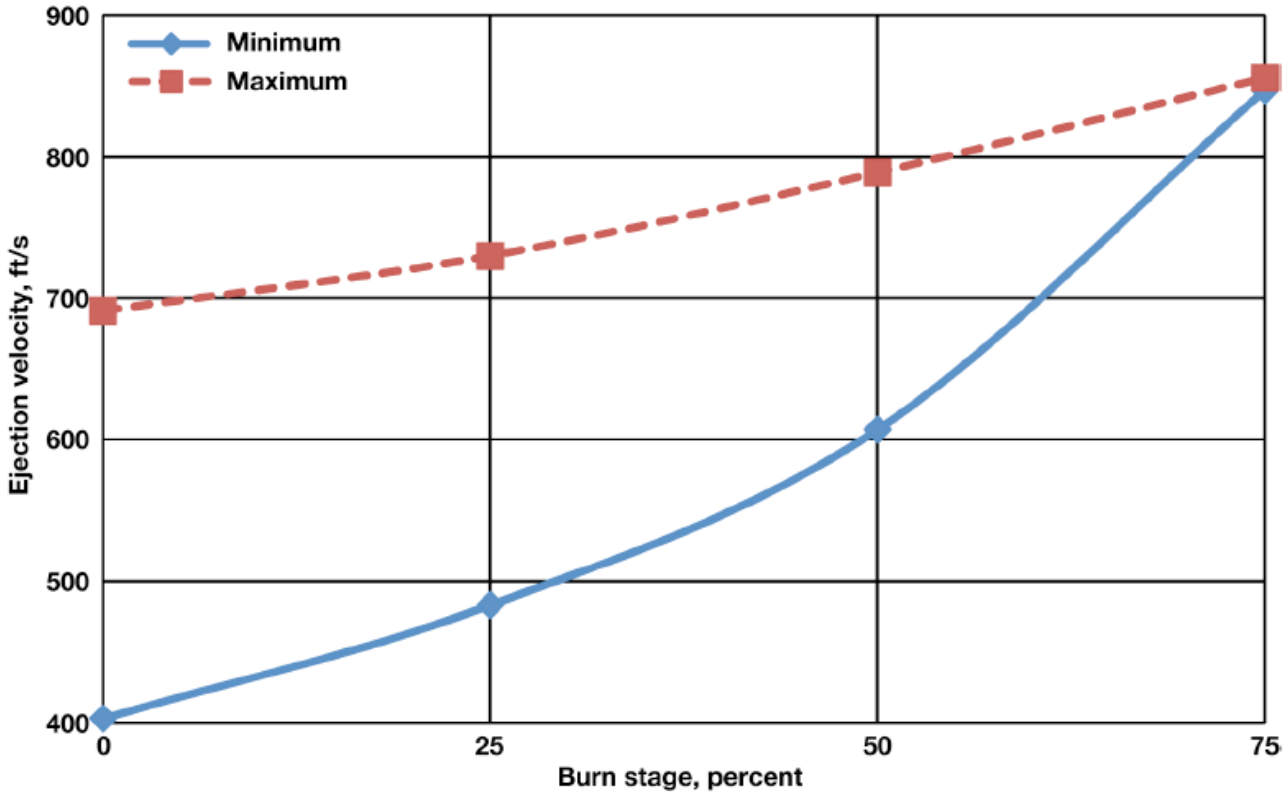
Results

- Key behavior is inverse relationship between fragment size and fragment ejection velocity
- As fragments become more massive, force is applied on a smaller area per unit mass
- This behavior accounts for two trends:
  - Decrease in velocity with increasing weight class
  - Increase in velocity with increasing burn stage

	Smallest Fragment		Largest Fragment	
Burn Stage	Mass (lbm)	Velocity (ft/s)	Mass (lbm)	Velocity (ft/s)
0%	0.43	690	42	400
25%	0.41	730	33	480
50%	0.31	790	23	600
75%	0.29	860	12	850

Results

- Minimum and maximum velocities converge towards later burn stages
- Converging behavior reflects reduction in propellant remaining at progressive burn stages



Assumptions, Suggested Future Work

- Assumptions
  - Applicability of statistical distribution model towards PA-1 Abort Motor
  - Effect of composite case on distribution model and velocity model
- Future Work
  - More robust distribution discretization method
  - Complete analysis for future AFT missions

Questions?

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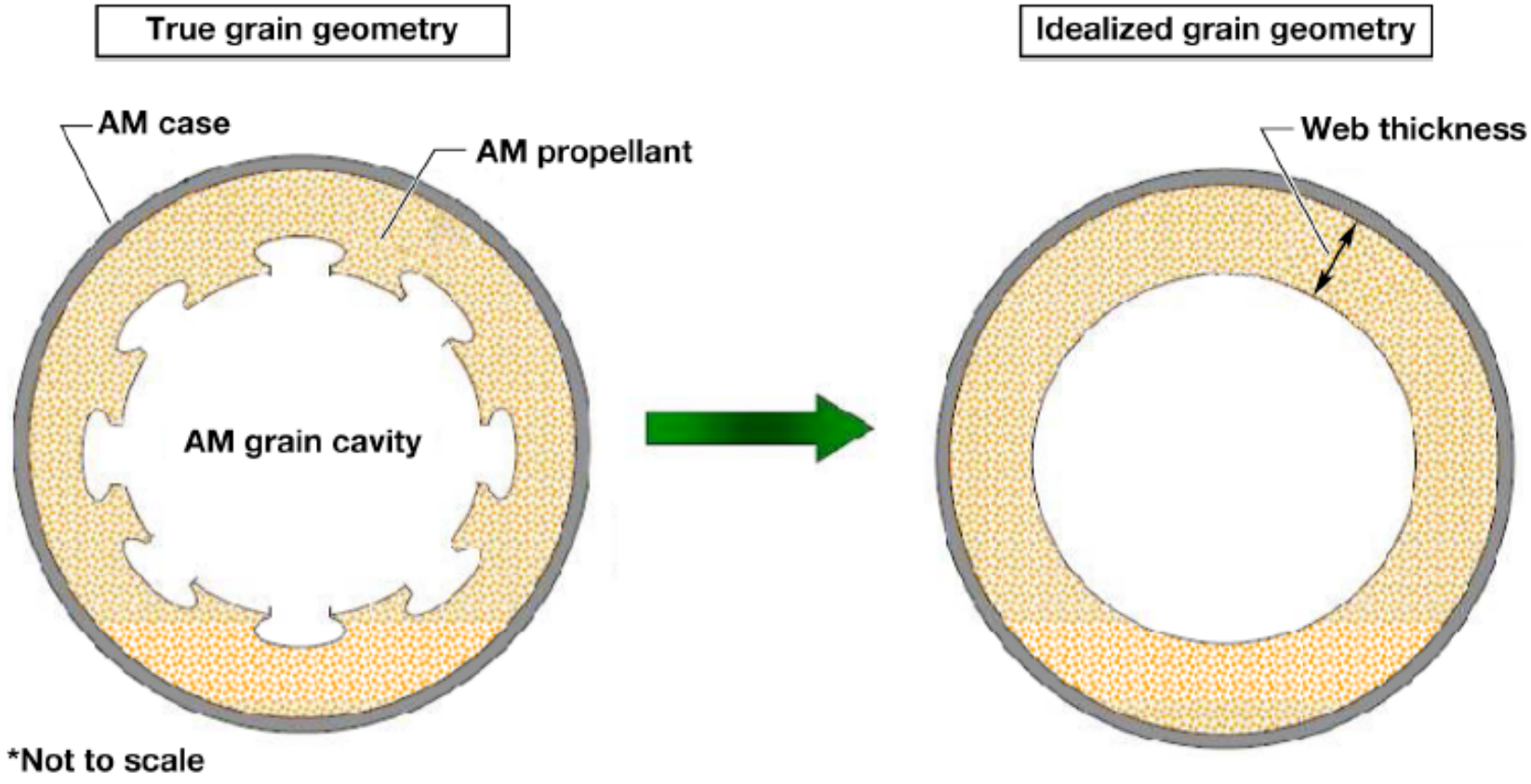
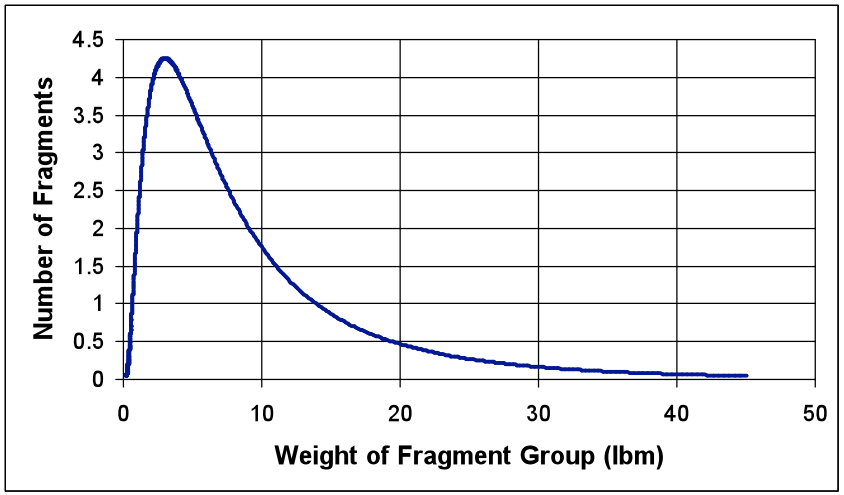
AM Propellant Grain Geometry



Fragment Class Clustering



Group Distribution

Class Distribution